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OPERATING INSTRUCTIONS FOR TYPE 544-B MEGOHM BRIDGE

FORM 458-C

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GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS

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OPERATING INSTRUCTIONS
FOR
TYPE 544-B
MEGOHM BRIDGE

PART 1
PURPOSE

The Type 544-B Megohm Bridge is a direct-current Wheatstone bridge for measuring high resistances. Adequate sensitivity for indicating the bridge balance is obtained from the use of a vacuum-tube voltmeter. Its controls are direct-reading in megohms.

RANGE AND ACCURACY The range of the bridge extends from 0.1 megohm to 1 megamegohm with errors varying from 3% upward. Using the main decade of the MEGOHMS dial, which is approximately logarithmic, the accuracy is 3% for the first three multiplier steps up to 100 MΩ, 6% to 1000 MΩ and 10% to 10,000 MΩ. Above 10,000 MΩ the error increases rapidly, becoming 30% at 100,000 MΩ. A resistance of 1 MMΩ (1,000,000 megohms) can be detected.

PART 2
INSTALLATION

ACCESSORIES SUPPLIED A flexible jack with lead is mounted in the cover for checking the internal standards as explained in Part 4, Section D.

One Type 274-M and one Type 274-ML Plug are enclosed with each instrument.

POWER SUPPLIES - The Type 544-B Megohm Bridge can be operated either from dry batteries or from either of two a-c power supplies. These power supplies are interchangeable and fit into the compartment at the rear of the cabinet. One of these power supplies is normally supplied with the bridge, properly mounted in the rear compartment, except that the tubes are protected. The detector tube for the bridge is considered to be a part of the power supply, because different tubes are required for battery or a-c operation. This tube is not plugged into its socket and will be found inside the rear compartment.

TYPE 544-P2, 90-VOLT A-C POWER SUPPLY

TUBES AND PARTS

- 2 - Type 6X5G Rectifier Tubes
- 2 - Type 874 Ballast Tubes
- 1 - Type 6K7G Detector Tube
- 1 - 200 Ω Galvanometer Shunt
- 6 - 1-ampere Fuses (Box of 5 extra)
- 1 - Attachment Cord

CONNECTIONS Remove the cover of the power supply compartment and also remove the bridge panel. Remove the protecting cartons from the four tubes in the power supply and see that they are seated in their sockets. Check the seating of the fuse.

Plug the Type 6K7G Detector Tube into its socket below the panel. See that the 200 Ω shunt is connected across the galvanometer terminals. Reconnect the Jones plug between power supply and bridge. Replace panel and cover and connect attachment cord.

TYPE 544-P3 500-VOLT A-C POWER SUPPLY

TUBES AND PARTS

- 1 - Type 6X5G Rectifier Tube
- 1 - Type 5U4G Rectifier Tube
- 1 - Type 6K6G Regulator Tube
- 1 - Type 6J5G Regulator Tube
- 2 - Type T-4-1/2 Ballast Tubes
- 1 - Type 4A1 Ballast Tube
- 1 - Type 6K7G Detector Tube
- 1 - 200 Ω Galvanometer Shunt
- 7 - 1-amp. Fuses (Box of 5 extra)
- 1 - Type 274-M Plug
- 1 - Attachment Cord

CONNECTIONS Remove the cover of the power supply compartment and also remove the bridge panel. Remove the protecting cartons from the five tubes in the power supply and see that they are seated in their sockets. Check the seating of the fuses.

Plug the Type 6K7G Detector Tube into its socket below the panel. See that the 200 Ω shunt is connected across the galvanometer terminals. Reconnect the Jones

plug between power supply and bridge. Replace panel and cover and connect attachment cord.

TYPE 544-P10 BATTERY POWER SUPPLY

TUBES AND PARTS

1 - Type 1D5G Detector Tube
2 - No. 6 Dry Cells
3 - 45 v Dry Batteries, Burgess 5308
1 - Battery Connector
1 - 2 kΩ Resistor to be used as a Battery Connector
1 - Wooden Battery-Separator
1 - Battery Cable with Jones Socket

CONNECTIONS Remove the cover of the power supply compartment and also remove the bridge panel. Check the arrangement and wiring of the batteries as shown in the battery diagram and cable color code of Figure 1. This figure also appears on the instruction sheet fastened in the cover. The 2 kΩ battery connector furnishes protection against a short circuit of the UNKNOWN terminals.

Plug the Type 1D5G Detector Tube into its socket below the panel. See that the galvanometer is not shunted. Reconnect the Jones plug between power supply and bridge. Replace panel and cover.

EXCHANGE OF POWER SUPPLIES The three power supplies are interchangeable. The two a-c power supplies are held down by three machine screws.

When the change is made between battery and a-c power supplies, the galvanometer shunt and the detector tube must be changed. The 200Ω galvanometer shunt is used with the a-c tube, Type 6K7G, in order to reduce its sensitivity to that of the battery tube, Type 1D5G, which is sufficiently sensitive for most uses. If greater sensitivity is desired, the shunt can be omitted. The battery tube, Type 1D5G, must NEVER be used with an a-c power supply. Its filament will be burned out instantly. If used with the 500-volt a-c power supply, the Type 4A1 Ballast Tube will also be burned out.

PART 3
MEASUREMENTS

ADJUSTMENT Ground the bridge at the terminal marked "G" in the upper left corner of the panel and swing the spring connector pivoted on the G terminal on the right side of the bridge to the LOW terminal.

With the control knob (CHECK-OPERATE-CHARGE) set at CHECK, throw all three switches at the rear of the panel to ON. (For battery operation it is unnecessary to throw the A.C. switch.) After about 10 seconds (immediately for battery operation), the galvanometer will deflect off scale to the left and then return toward zero. Bring the galvanometer to zero by turning the ZERO ADJUST knob in the direction in which the pointer of the galvanometer should move. At least 2 minutes (1 minute for battery operation) are required for all filaments to attain equilibrium.

CHECKS Swing the MULTIPLY BY switch over its range. The galvanometer may deflect a half division to the right with this switch set at 1000 because of positive ion grid current. A deflection exceeding one division generally indicates excessive grid current and the detector tube should be replaced. Occasionally the grid current is high just after the tube is turned on and decreases to a normal value after 10 or 20 minutes. Large electrostatic fields near the bridge will also cause the galvanometer to deflect to the right with the MULTIPLY BY switch set at 1000. This effect will be accentuated when a long unshielded lead is connected to the + UNKNOWN terminal. (See Part 4, Section A, Extraneous Potentials.)

A. GROUNDED RESISTOR

Procedure

Swing the spring connector pivoted on the G terminal to the LOW terminal. Connect the resistor to be measured to the UNKNOWN RESISTOR terminals with its ground side connected to the LOW terminal. After these connections are made the ground connection mentioned under ADJUSTMENT becomes unnecessary.

With the control knob set at CHECK bring the galvanometer to zero by means of the ZERO ADJUST knob. Throw the control knob to OPERATE and return the galvanometer to zero by adjustment of the MULTIPLY BY switch and the MEGOHMS dial. A low resistance deflects the galvanometer to the left, a high resistance to the right. Hence the MEGOHMS dial should be turned in the direction in which the pointer of the galvanometer should move. The MULTIPLY BY switch, on the other hand, should be turned in the opposite direction. In general, that setting of the MULTIPLY BY switch should be chosen which leaves

the MEGOHMS dial set in its main decade from 1 to 10.

The resistance of the unknown resistor in megohms is the product of the setting of the MULTIPLY BY switch and the reading of the MEGOHMS dial.

Accuracy

The accuracy of this resistance reading is 3% between 0.1 and 100 megohms, 6% between 100 and 1000 megohms and 10% between 1000 and 10,000 megohms, provided the MEGOHMS dial is set on its main decade between 1 and 10. The accuracy of the two shorter decades above 10 is determined by the spacing of the graduations.

The errors involved in these measurements come mainly from the errors of calibration or adjustment of the resistors in the arms of the bridge. Numerical values for these errors are given in Part 5, Section A. The errors of the standard resistors N used with the MULTIPLY BY switch set at 100 and 1000 are given as corrections to the reading of the MEGOHMS dial on the cover of the bridge. Methods for checking these errors and reducing the errors of the MEGOHMS dial are given in Part 4, Sections D and E.

Precautions

Since all high resistances have imperfect insulation, they will have capacitance and dielectric absorption. They may also have d-c and a-c voltages induced in them by external electrostatic fields. These various conditions indicate their presence by their effect on the initial zero adjustment or on the bridge balance. If the galvanometer zero drifts in either direction, in either its initial adjustment or in the final bridge balance, or if this zero is different with the control knob in CHECK and CHARGE positions, one or more of the above conditions exists. The proper procedure to follow is discussed in Part 4, Section A.

B. UNGROUNDED RESISTOR

If the resistor to be measured has neither terminal grounded, its resistance may be measured by the method of Section A provided it can be entirely supported on the UNKNOWN RESISTOR terminals.

When the unknown resistor has its own insulating supports, it is no longer a two-terminal resistor, but is a three-terminal resistor, ground being the third terminal. It has three resistances, as shown in Figure 4, its direct resistance R_D and its two terminal resistances R_1 and R_2. When such a resistor is connected to the UNKNOWN RESISTOR terminals, that terminal resistance which is associated with the terminal connected to the LOW terminal is shorted and the resistance measured by the bridge is that of the direct resistance and the other terminal resistance in parallel.

The direct resistance R_D can be measured by swinging the ground connector to the GUARD terminal and balancing the bridge as described in Section A. A more complete discussion of the measurement of direct resistance is given in Part 4, Section B.

PART 4
OTHER USES

A. RESISTANCE OF CONDENSERS

While the resistance of a condenser is measured in the same manner as a pure resistance, as described in Part 3, Section A, certain extra precautions must be taken because of the large capacitance which is in parallel with the resistance.

Functional wiring diagrams of the bridge are shown in Figure 3. With the control knob set in the CHECK position, the unknown condenser connected to the UNKNOWN RESISTOR terminals is placed in parallel with the standard resistor N in the grid circuit of the detector tube. If there is no residual charge in the condenser, the setting of the ZERO ADJUST knob will be the same as if the parallel condenser were not present. Any residual charge will cause the zero of the galvanometer to drift until this charge is completely dissipated.

When the control knob is turned to the OPERATE position, the bridge voltage is applied to the condenser through the standard resistor N. If the time constant RC of condenser and resistor is only a few seconds, steady state conditions will be set up in the time necessary to operate the various controls. For the largest standard, 100 MΩ, used when the MULTIPLY BY switch is set at 1000, the condenser may have a capacitance of 0.01 μf for a time constant of 1 second and 0.1 μf for a time constant of 10 seconds.

When the time constant is greater then 5 seconds, time will be saved by turning the control knob to the CHARGE position. This removes the standard resistor N from the charging circuit and applies

directly to the condenser a voltage within 10% of that which it will finally have with the control knob set at OPERATE. This process may be repeated as often as desired, rebalancing the bridge each time that the control knob is set at OPERATE.

A time constant of 100 seconds is about as large as it is convenient to use. After each adjustment of the bridge, sufficient time must elapse to show in which direction the galvanometer is moving and this time is proportional to the time constant. This consideration sets an upper limit of perhaps 10 μf with the MULTIPLY BY switch set at 100, and 1 μf with this switch set at 1000.

Since it is impossible to check the zero of the galvanometer in the CHECK position without completely discharging the condenser, the CHARGE position can be used for this purpose, whenever it has been shown that there are no extraneous potentials induced in the condenser, as explained below.

Dielectric Absorption

All solid dielectric condensers have dielectric absorption. It is particularly noticeable in those condensers having a laminated structure. In addition to the normal charge, there is a volume charge which slowly diffuses into the material, requiring minutes, hours and even days to attain equilibrium. The charging current which flows is added to the steady leakage current and gives an instantaneous resistance which is lower than the true leakage resistance.

This phenomenon may be studied by maintaining the bridge balance by continual adjustment of the MEGOHMS dial. The resistance at any time may be observed by ceasing to maintain the bridge balance after that instant and noting the reading. The necessity of reading a continually moving pointer at a specified time is thus avoided. The bridge may then be brought into balance for the next reading. The initial zero adjustment of the bridge must be made with the control knob in the CHECK position so that all resistance values may start from the uncharged condition of the specimen.

When dielectric absorption exists, it has been customary to observe the instantaneous resistance one minute after the application of the charging voltage and call that the insulation resistance. Such a resistance value is, however, merely a measure of dielectric absorption and may have little relation to true insulation resistance. The rate of change of resistance with time is a better measure of insulation resistance, because it suggests by its magnitude a possible upper limit of resistance.*

If the time constant of the unknown condenser and the standard resistor is greater than a few seconds, the initial charging current will not have ceased before observations on the dielectric absorption are begun. The actual values of resistance as observed will then depend somewhat on the setting of the MULTIPLY BY switch. It is usually advisable to use as small a multiplying factor as possible and allow the setting of the MEGOHMS dial to pass up into the second decade. It is sometimes preferable to throw the control knob to the CHARGE position for a definite time interval, say one minute, before passing to the OPERATE position. This procedure eliminates the initial charging current, but leaves the first part of the curve dependent on the setting of the MEGOHMS dial while the charging took place.

The time required to dissipate a volume charge is much greater than the charging time, even if the terminals of the condenser are shorted, because the voltage acting on the charge is no longer constant but decreases with time. The presence of a volume charge is shown by a shift in the zero balance of the bridge for the CHECK position from its normal value, which is essentially that for the control knob in the CHARGE position. The gradual disappearance of this charge may be observed as a drift in the galvanometer zero for the CHECK position.

Charge and Discharge Current

The charging current flowing into the condenser at any instant may be calculated from the observed resistance P, the standard resistance N, and the voltage E applied to the bridge.

$$I = \frac{E}{N+P} = \frac{10E}{M(1 + 10D)} \quad \mu a \qquad (1)$$

where M is the setting of the MULTIPLY BY switch and D the reading of the MEGOHMS dial. The voltage E applied to the bridge may be measured by a high resistance voltmeter connected across the BRIDGE terminals. The voltmeter resistance must be sufficiently high (at least 1 MΩ) so that its application does not affect the bridge voltage.

The discharge current flowing out of a condenser which has been previously charged, may be measured in the

*R. W. Wiesman, "Insulation Resistance of Armature Windings", Electrical Engineering, June, 1934.

Murphy & Morgan, "The Dielectric Properties of Insulating Materials", Bell System Technical Journal, October, 1939.

following manner. A piece of mica or other thin but high-resistance insulator is slipped in between contacts 2 and 4 of the control switch when set in the OPERATE position. These contacts are shown in Figure 9 and are the two nearest the panel in the outside row. The LOW terminal is then connected to the + BRIDGE terminal. The charged condenser is connected to the UNKNOWN RESISTOR terminals in a direction reversed from its connection during charge. The bridge will balance in the same manner as during the charging cycle. The resistance read in the normal way is the resistance which the condenser would have if the voltage across it were normal. The discharge current is given by Equation (1).

Extraneous Potentials

Unshielded resistors and condensers, especially those having large physical dimensions, may have a voltage induced in them by an external electrostatic field. This is usually an alternating potential, because alternating electric fields at the power supply frequency are usually present in laboratories, factories and power houses. An appreciable voltage may also be induced in the lead from the high UNKNOWN terminal to the resistor if this lead is long and unshielded, particularly if it is allowed to lie next to the attachment cord. The effect of this induced voltage is to change the effective bias of the detector tube and hence the galvanometer deflection. As shown in Figure 3, the unknown and standard resistors are connected in parallel in the grid circuit of the detector tube in exactly the same way in both the CHECK and OPERATE positions. If then the zero adjustments are made with the control knob in the CHECK position, the effect of the induced voltage will be eliminated. Even a large induced voltage will not cause a direct error in the bridge balance, provided the zero adjustment can still be made.

The existence of induced voltage is disclosed by a difference in the zero balance for the CHECK and CHARGE positions. Alternating voltages affect the balance as well as direct voltages, because the tube rectifies as well as amplifies.

B. DIRECT RESISTANCE

The direct resistance of a three-terminal resistor may be measured by connecting the third terminal to the GUARD terminal, as shown in Figure 5. There are three cases dependent on the method of grounding of the three-terminal resistor. For each of these the bridge must be grounded at a different junction.

1. One Main Terminal Grounded

The grounded terminal is connected to the LOW terminal and the spring connector pivoted on the G terminal swung to LOW. This connection is used for grounded insulators and cables when the direct resistance to ground of some terminal or lead is wanted. All other terminals and leads are connected to the GUARD terminal. The third terminal may also be a guard electrode provided to remove the effect of leakage over the surface of the insulation or to prevent fringing at the edges of the electrodes. When the bridge is balanced the GUARD and high terminals are at the same potential. The electrodes may be mercury confined in rings as shown in Figure 6, lead foil pressed closely to the surface of the insulator, or solid metal shaped to fit. Intimate contact is essential for obtaining correct results. Air pockets or voids are almost perfect insulators. For the same reason petrolatum should not be used to make the lead foil adhere.

2. Third Terminal Grounded

The larger or outside main terminal is connected to the LOW terminal and the spring connector pivoted on the G terminal swung to GUARD. This connection is used for insulators mounted on grounded metal and cables with grounded sheaths when the direct resistance between two terminals or leads held in the insulation is wanted. All other terminals and leads are connected to the grounded GUARD terminal.

3. No Terminal Grounded

The network is strictly no longer a three-terminal resistor, but a four-terminal resistor with ground as the fourth terminal. The three terminals are connected to +, LOW and GUARD terminals in the order desired for the measurements. The spring connector pivoted on the G terminal is swung free and the + BRIDGE terminal grounded. This connection is rarely needed because it is almost always possible to ground one of the three terminals of a network without altering a given direct resistance.

Precautions

The terminal resistances R_1 and R_2 of Figure 4 become a part of the bridge, R_2 shunting the B arm having 100 kΩ resistance, and R_1 shunting the vacuum-tube voltmeter. They must not be of such low value as to introduce errors into the bridge balance. R_2 should be at least

100 times B and preferably 1000 times, 10 MΩ for the former and 100 MΩ for the latter case. R_1 does not affect the bridge balance directly but decreases the sensitivity of this balance. It should not be much lower than the input resistance of the tube, which is about 10 kMΩ. The effect of 100 MΩ is very noticeable.

C. TERMINAL RESISTANCE

The terminal resistances of a three-terminal resistor can be measured by considering them as direct resistances and measuring them by the methods of Section B. The same three types of grounding as are described in that section may occur. Care must be taken that those resistances which become terminal resistances for this measurement are sufficiently large, as defined under Precautions in Section B.

D. INTERNAL STANDARDS

The internal standards used in the N arm of the bridge when the MULTIPLY BY switch is set at 100 and 1000 can be measured in terms of the lower resistance standards of the N arm by using the flexible jack stored in the cover. These two resistors are provided with plug terminals mounted on the switch, which can be reached by the flexible jack through a hole in the panel. The two plug terminals are arranged in the same order from left to right as the switch positions. The other end of the jack is connected to the LOW terminal.

With the jack on the left terminal and the MULTIPLY BY switch set at 10, the standard resistor for the 100 position is measured in terms of the standard for the 10 position with the MEGOHMS dial at approximately 1. With the jack on the right terminal the standard resistor for the 1000 position is measured in terms of the 10-position standard when the MULTIPLY BY switch is set at 10 and in terms of the 100-position standard when the MULTIPLY BY switch is set at 100. The standard resistor for the 10 position is adjusted to 0.25% and the MEGOHMS dial is calibrated to 2%. These measurements are thus accurate to 3%. Greater accuracy can be attained by the use of an external decade resistor as explained in Section E.

E. EXTERNAL DECADE RESISTOR

The logarithmic resistor, A, controlled by the MEGOHMS dial may be replaced by a suitable decade resistor by opening the A arm at some point (by placing a piece of paper or other thin insulator under the contact arm of the logarithmic resistor) and connecting the decade resistor to the GUARD and + BRIDGE terminals. The case of the decade resistor should be grounded. The bridge is then balanced by means of this decade resistor and the MULTIPLY BY switch.

The Type 602-J Decade-Resistance Box* covers the same range as the logarithmic resistor with an accuracy of 0.1% for the highest decade. The use of Type 602-M and 602-N Decade Resistance Boxes* allows the range of the bridge for which this accuracy of 0.1% applies to be extended one decade above and below the normal range, for the former to 10 kΩ, for the latter to 100 kMΩ.

The three lower standards in the N arm and the resistor in the B arm are adjusted to an accuracy of 0.25%. Hence readings can be made with the MULTIPLY BY switch set at 0.1, 1, 10 to an accuracy of 0.6%. The two higher standards in the N arm can be measured by the method of Section D, using a suitable decade resistor, to an accuracy of 0.6%. Hence readings with the MULTIPLY BY switch set at 100 and 1000 will have an accuracy of 1.0% when the proper correction for the standard is applied.

The sensitivity of the bridge balance varies by almost 10 to 1 over the main decade of the MEGOHMS dial as arm A decreases from 10 kΩ to 1 kΩ. The 200Ω shunt placed across the galvanometer decreases its sensitivity by a factor of 4.3. This figure is approximately the ratio of sensitivities of the a-c and battery detector tubes Types 6K7G and 1D5G. The sensitivity of bridge balance with battery tube or with a-c tube and galvanometer shunted is 1.3% at the 10 end of the main decade with 100 volts applied to the bridge. The sensitivity is improved to about 0.3% with 500 volts applied to the bridge or with 100 volts, a-c tube and shunt removed. A maximum sensitivity of 0.06% holds for the latter case with 500 volts. For resistances in the A arm less than 1 kΩ, the sensitivity expressed in per cent increases to 0.6% for 100Ω, 6% for 10Ω, 60% for 1Ω.

F. SUBSTITUTION METHODS

Two resistors having resistance values in the same decade may be compared with one another with an error which is frequently much less than that of a direct measurement. The entire error is that of reading the MEGOHMS dial, 2% for each setting. The maximum error of the comparison is 4%, which is less than that of a direct reading with the MULTIPLY BY switch set at 100 and 1000.

* See General Radio Catalog for data.

When the two resistors are nearly equal, the settings of the MEGOHMS dial are nearly the same and the error is reduced to that of reading the difference of the two settings.

When an external decade resistor is used, as suggested in Section E, the maximum error of the comparison is 0.2%, provided that this is not limited by the sensitivity of the bridge balance. For nearly equal resistors the error is determined entirely by the precision of balance.

Intercomparison of Standards

Sets of standards may be compared by means of an external decade resistor to an accuracy of about 0.1% over the range from 10 kΩ to 10 kMΩ. For this comparison it is desirable to have pairs of standards of values 1, 2, 5 per decade. Any other combination will suffice which allows each standard to be compared directly with a number of those of lower value connected in series. The two 1's are first compared, then the 2's with the 1's in series. Next the 5's are compared with the two 2's and a 1 in series and finally the 10's, 1's of the next decade, are measured in terms of the two 5's in series.

An important source of error will occur if the resistors have an appreciable voltage coefficient of resistance. Each resistor is first measured so as to have across it nearly the full voltage of the bridge. Then it is placed in series with other resistors so that it has across it one-half its former voltage or less. If the voltage coefficient of resistance is of considerable magnitude, it should be measured as explained in Section G. Corrections may then be applied in order to correct the measured resistance to a constant voltage.

G. BRIDGE VOLTAGE

The input terminals of the bridge appear on the left side of the panel marked + - BRIDGE. The voltage across the bridge can be measured by connecting a high resistance voltmeter to these terminals. The resistance of this voltmeter should be high (at least 1 MΩ) compared to the bridge resistance. The minimum allowable depends also on the regulation of the power supply.

An upper limit of 500 volts across the bridge is set by the power dissipation of the B arm. None of the other arms of the bridge can be overloaded except when the control switch is set in the CHARGE position. For this position the unknown resistor is connected directly across the B arm. If this resistor happens to have a low resistance or is shorted, the full voltage of the power supply is placed across the logarithmic resistor, which forms the A arm, whose maximum current is 40 ma. Under these conditions this current will be exceeded for 100 volts across the bridge if the MEGOHMS dial reads more than 4, for 500 volts if the dial reads more than 0.8, which is the minimum reading. It is, therefore, desirable that the power supply have considerable regulation. The short circuit current of the Type 544-P3 500-volt a-c Power Supply is 12 ma at 500 volts and 6 ma at 100 volts; that of the Type 544-P2 90-volt a-c Power Supply, 9 ma. When dry batteries are used a protective resistance should be placed in series, 2 kΩ for 90 volts, 5 kΩ for 200 volts, 12 kΩ for 500 volts. A 2 kΩ resistor is supplied with the Type 544-P10 Battery Power Supply for this purpose.

The voltage applied to the bridge is affected slightly by the setting of the MEGOHMS dial, because of the regulation inherent in all power supplies as just described. The decrease in voltage as the dial is turned from 1 to 10 amounts to 0.3% for Type 544-P10, 1% for Type 544-P2 and for Type 544-P3, 2% at 100 volts and 5% at 500 volts. With the MULTIPLY BY switch set at .1, the resistance of the N and P arms became comparable with that of the A and B arms. In the extreme case, when the unknown resistor is 100 kΩ, the resistance of the bridge is halved to 55 kΩ. For this condition the voltage across the bridge is reduced by 2% for the Type 544-P10, 8% for Type 544-P2 and for Type 544-P3, 12% at 100 volts and 29% at 500 volts. The changes for the Type 544-P3 Power Supply are smaller than might be expected in view of its small short circuit current because the series triode regulator tube tends to maintain constant current.

The voltage across the unknown resistor P varies with the setting of the MEGOHMS dial from 90% to 100% of the bridge voltage according to the expression

$$E_P = \frac{B}{A+B} E = \frac{10D}{100 + 10D} E = \frac{E}{1 + \frac{1}{10D}} \quad (2)$$

where D is the reading of the MEGOHMS dial.

PART 5
CONSTRUCTION

A. RESISTANCE ARMS

The schematic wiring diagram of the bridge is shown in Figure 2 (also on the instruction sheet mounted in the cover). The complete wiring diagram is shown in Figure 11. It is a simple d-c Wheatstone bridge with unequal arms controlled by the MULTIPLY BY switch for the N arm and by the MEGOHMS dial for the A arm. All of the resistors are wire wound except the two highest resistances in the N arm, which are metallized filaments. Their resistance values, errors of adjustment, temperature coefficient and voltage coefficient are given in Table I. The error given for the A arm is for the main decade of the dial over which the logarithmic shape of the resistor keeps the fractional accuracy essentially constant. Its resistance in kilohms at any setting is ten times the reciprocal of the dial reading.

B. VACUUM-TUBE VOLTMETER

Bridge balance is indicated by means of a vacuum-tube voltmeter whose connections are shown schematically in Figure 7 and completely in Figure 11. Supercontrol pentodes, Type 1D5G and Type 6K7G, are used in order to obtain sufficient mutual conductance at the low plate voltage necessary to keep the grid current less than 100 μμa. Grid, screen and plate voltages are obtained from a voltage divider having a total resistance of 6 kΩ and carrying a current of 7.5 ma when used with Type 544-P3 and Type 544-P10 Power Supplies and 6 ma when used with Type 544-P2 Power Supply. Plate voltages are 29 volts and 24 volts respectively. The effective mutual conductances of the two tubes are 60 micromhos for Type 1D5G and 250 micromhos for Type 6K7G. The 200 Ω galvanometer shunt used with the a-c tube equalizes these mutual conductances. It may be removed in order to obtain maximum sensitivity for such measurements as those described in Part 4, Section F.

The galvanometer has a center zero with a current sensitivity of 100 μa full deflection and a resistance of 660 Ω. A scale division corresponds to 4 μa. Increasing the plate current produces a positive deflection of the galvanometer. The rheostat controlled by the ZERO ADJUST knob balances out the plate current from the galvanometer, counter-clockwise motion corresponding to increased plate current. The pointer of this knob should be approximately within the span of the arrow engraved on the panel for the battery tube and within 15° of a left horizontal position for the a-c tube.

A resistance of 10 MΩ is placed in the grid circuit to prevent an excessive voltage being placed on the grid of the tube when the bridge is unbalanced. A 0.001 μf condenser connected from grid to cathode acts with the 10 MΩ resistor as a resistance-capacitance filter to attenuate by a factor of 4 any alternating voltage induced in the unknown resistor and its leads.

C. SWITCHES

Parts of the control switch CHECK-OPERATE-CHARGE, the MULTIPLY BY switch and the whole of the bushing of the + UNKNOWN terminal are connected directly across the unknown resistor. They are, therefore, made of low-loss bakelite (BM-262 Natural) which has a very high insulation resistance, usually here greater than 10 MMΩ. Any leakage over these switches or the bushing will show as a measurable resistance when the bridge is balanced with the unknown resistor disconnected.

D. POWER SUPPLIES

A-C Operation

Type 544-P2 90-Volt A-C Power Supply

The connections of the power supply are shown schematically in Figure 8, and completely in Figure 12. Its component parts are listed in Part 2. The Type 874 Ballast Tubes maintain a nearly constant voltage of 90 volts across their terminals. Their current is about 20 ma with 110 volts applied from the line. They will regulate over a range of line voltage from 100 to 130 volts. The a-c ripple appearing across the output terminals of the two filter systems should not be greater than 0.8 volts for the bridge supply and 0.3 volts for the tube supply. Voltages greater than these usually indicate defective ballast tubes.

The power drawn from the line is 25 watts at 110 volts, increasing to 35 watts at 130 volts. There is no change with frequency down to 40 cycles. Frequencies lower than 40 cycles must not be used.

Type 544-P3 500-volt A-C Power Supply

The connections of this power supply are shown schematically in Figure 9 and completely in Figure 13. Its com-

ponent parts are listed in Part 2. The two series triodes maintain constant current in their respective circuits by varying their plate resistances inversely with the line voltage. Their cathodes are connected to voltage dividers whose two parts are adjusted to be in the ratio of the amplification factor of the tubes, 20 for the Type 6J5G Tube in the bridge supply and 6 for the Type 6K6G Tube in the detector supply. Their grids are connected to voltage dividers placed across neon tubes, which maintain a constant voltage of about 55 v.

The bridge current is 5 ma and the detector plate current 7.5 ma. These currents are stabilized against line voltage changes by adjusting the cathode voltage dividers R-2 and R-1 so that no change in current occurs when line voltage changes from 130 volts to 100 volts. The change in line voltage is most easily made by means of a Type 200-B or 200-C Variac. If a Variac is not available, the voltage applied to the bridge can be decreased by 10% by inserting a resistance of 30Ω. The currents are then brought to their correct values by adjusting the grid voltage dividers R-4 and R-3. All of these voltage dividers are so wired that turning them clockwise causes the output currents to increase. The output currents are measured by opening the shorting links on the terminal board which is mounted over the transformer, those for the bridge being marked 500 V and those for the detector being marked DET, and inserting a suitable milliammeter. These adjustments have all been made for the tubes supplied.

For the nominal bridge current of 5 ma the voltage across the bridge is 500 volts with the MEGOHMS dial set at ∞. As the setting of the dial is decreased to 1 the bridge resistance increases from 100 kΩ to 110 kΩ. The bridge current decreases but only by 4%, since the power supply is stabilized only for changes in line voltage and not for changes in load. The voltage across the bridge increases by 5%, while the voltage across the unknown resistor decreases by the same amount as the current, 4%.

Shunt and series resistors controlled by shorting links on the terminal board are provided for obtaining voltages other than 500 v for the bridge supply. The condition to be satisfied is that the load presented to the power supply shall be 100 kΩ regardless of the resistance or voltage of the bridge. The resistors used are shown in Figure 13. For a 100 kΩ bridge the links should cover the label "500 V" in order to obtain 500 volts across the bridge. Placing the links over the labels "100 V" gives 100 volts across the bridge. Intermediate voltages between 500 v and 300 v can be obtained by adjusting voltage divider R4 in a counterclockwise direction. Further reduction to 200 v can be obtained by adjusting voltage divider R2 counterclockwise. Although this last adjustment disregards the amplification constant condition, the stability is not noticeably impaired at this low voltage level. Provision is also made for supplying a bridge having a resistance of 1 MΩ.

The a-c ripple appearing across the output terminals of the power supplies is not greater than 0.6 volts for the bridge supply and 2.8 volts for the detector tube. The power drawn from the line is 55 watts at 115 volts, increasing to 64 watts at 125 volts. There is no large change with frequency down to 40 cycles. Frequencies lower than 40 cycles must not be used.

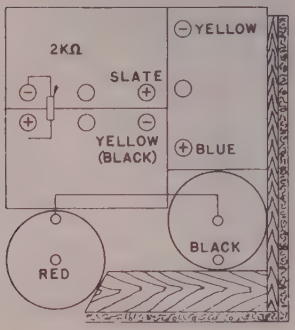

Figure 1. Arrangement of batteries in rear compartment with color code of cable.

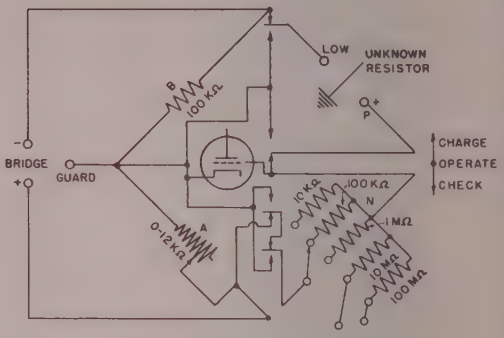

Figure 2. Schematic Wiring Diagram.

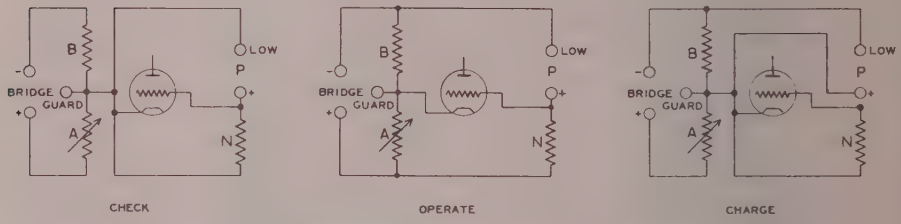

Figure 3. Connections of Type 544-B Megohm Bridge for three positions of control knob.

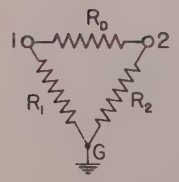

Figure 4. Direct resistance with two terminal resistances to ground.

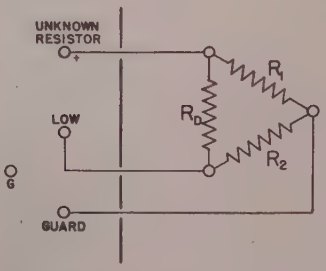

Figure 5. Bridge connections for measurement of direct resistance.

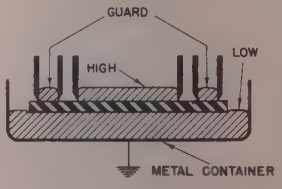

Figure 6. Mercury Electrodes.

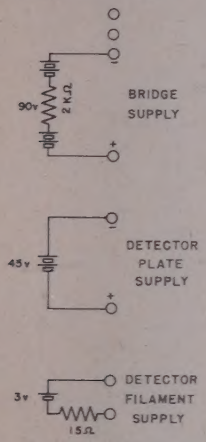

Figure 10. Schematic diagram of battery supply. For arrangement of terminals see Figure 11.

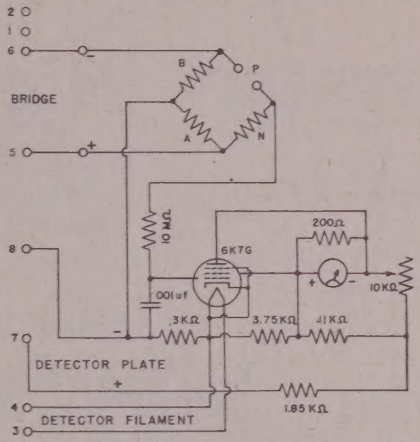

Figure 7. Schematic diagram of vacuum-tube voltmeter and bridge.

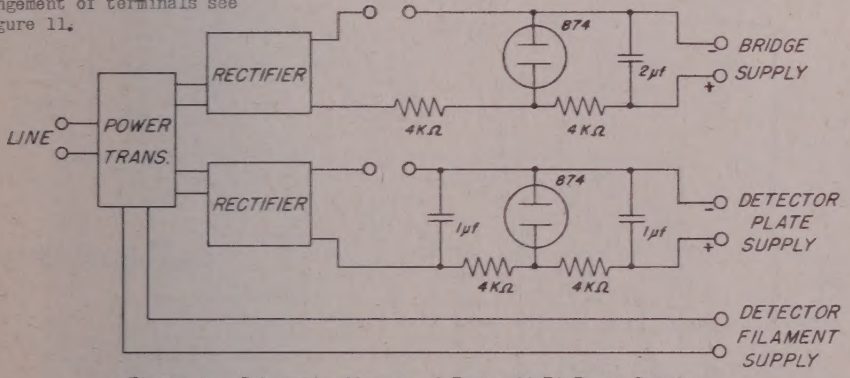

Figure 8. Schematic diagram of Type 544-P2 Power Supply.

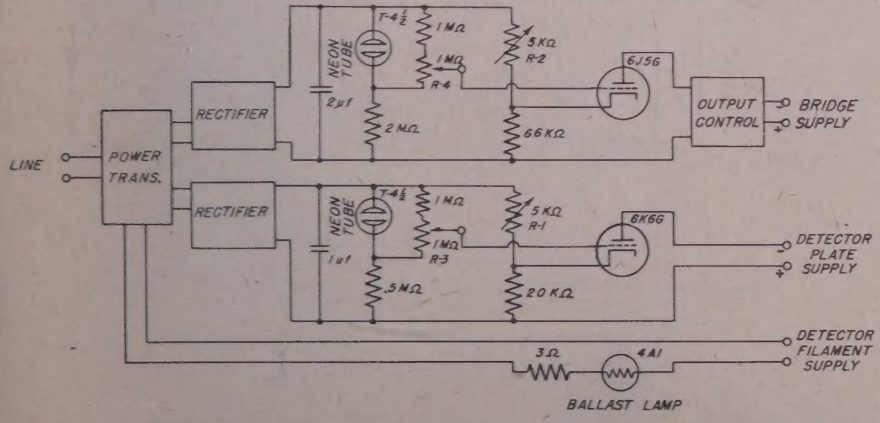

Figure 9. Schematic diagram of Type 544-P3 Power Supply.

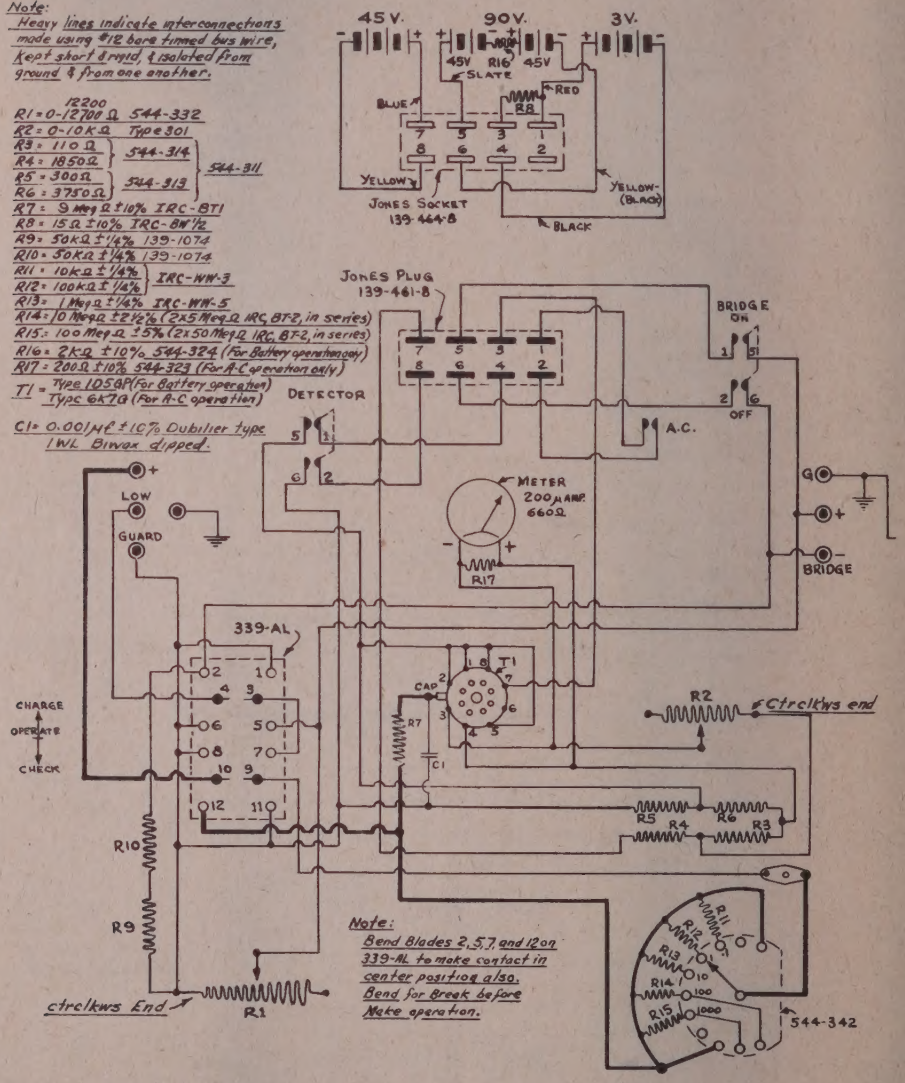

Figure 11. Complete wiring diagram of Type 544-B Megohm Bridge. At the top is shown the arrangement of terminals for battery power supply.

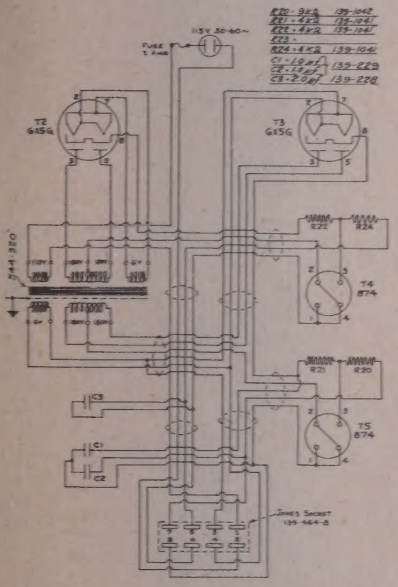

Figure 12. Complete wiring diagram of Type 544-P2 Power Supply.

TYPE 544-P3

PARTS LIST

Resistors

R-1 = 5 kΩ
R-2 = 5 kΩ
R-3 = 1 MΩ
R-4 = 1 MΩ
R-5 = 33 kΩ
R-6 = 33 kΩ
R-7 = 1 MΩ
R-8 = 2 MΩ
R-9 = 2 MΩ
R-10 = 1 MΩ
R-11 = 0.5 MΩ
R-12 = 2 MΩ
R-13 = 20 kΩ
R-14 = 6 kΩ
R-15 = 80 kΩ
R-16 =
R-17 = 25 kΩ
R-18 = 30 Ω
R-19 = 6 Ω

Condensers

C-1 = 2.0 μf
C-2 = 1.0 μf
C-3 = 1.0 μf

Transformer

T-1 = G.R.Co. 365-410-2

Fuses

F-1 = 1 amp. Type 7AG or 8AG
F-2 = 1 amp. Type 7AG or 8AG

Tubes

V-1 = RCA Type 6X5G
V-2 = RCA Type 5U4G
V-3 = RCA Type 6J5G
V-4 = RCA Type 6K6G
V-5 = Westinghouse T-4-1/2 (139-949)
V-6 = Westinghouse T-4-1/2 (139-949)
V-7 = Sylvania Type 4A1

V5 & V6 CAN BE REPLACED BY NE-48's

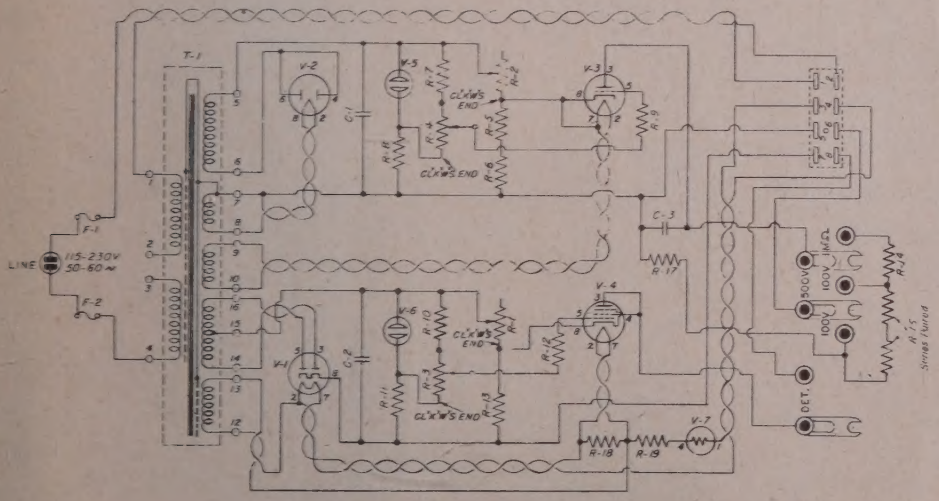

Figure 13. Complete wiring diagram of Type 544-P3 Power Supply.

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